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Barrett

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(54) **LOW-HEIGHT, LOW-COST, HIGH-GAIN ANTENNA AND SYSTEM FOR MOBILE PLATFORMS**

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(63) Continuation of application No. 08/932,190, filed on Sep. 17, 1997, now Pat. No. 5,973,647.

(51) **Int. Cl.**[7] **H04B 7/15**

(52) **U.S. Cl.** **455/11.1**; 455/13.1; 455/431; 455/456.1

(58) **Field of Search** 455/11.1, 456, 455/457, 13.1, 430, 13.2, 431, 41, 456.1–456.6, 41.1–41.3; 398/115

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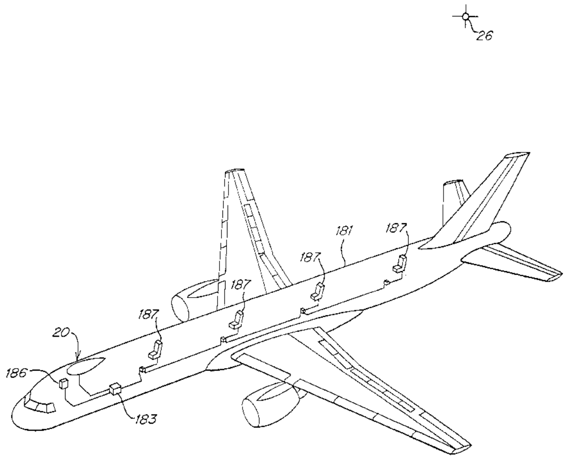
(57) **ABSTRACT**

A leaky waveguide antenna array that receives and/or transmits electromagnetic signals includes a plurality of radiation waveguides disposed in parallel to each other on a surface plane to form the antenna array. A feed waveguide is located below the surface plane and provides an electromagnetic signal to the plurality of radiation waveguides and/or receives a plurality of electromagnetic signals from the plurality of radiation waveguides and provides a composite electromagnetic signal at an output of the feed waveguide. Each of the plurality of radiation waveguides has a waveguide axis and includes a plurality of apertures arranged in a direction of the waveguide axis. The feed waveguide includes a first section of waveguide having a first end connected to an input/output port. The first section of waveguide has a height substantially the same as the height of each of the plurality of radiation waveguides and the first section of waveguide has a second end coupled to a first junction point. The first junction point transitions from the first section of waveguide to a second section of waveguide and a third section of waveguide that each have a height that is substantially half of the height of the first section of waveguide. The second section of waveguide transitions with an upward sloping ramp to the substantially half height of the first section of waveguide. The third section of waveguide transitions with a downward sloping ramp to the substantially half height of the first section of waveguide.

25 Claims, 9 Drawing Sheets



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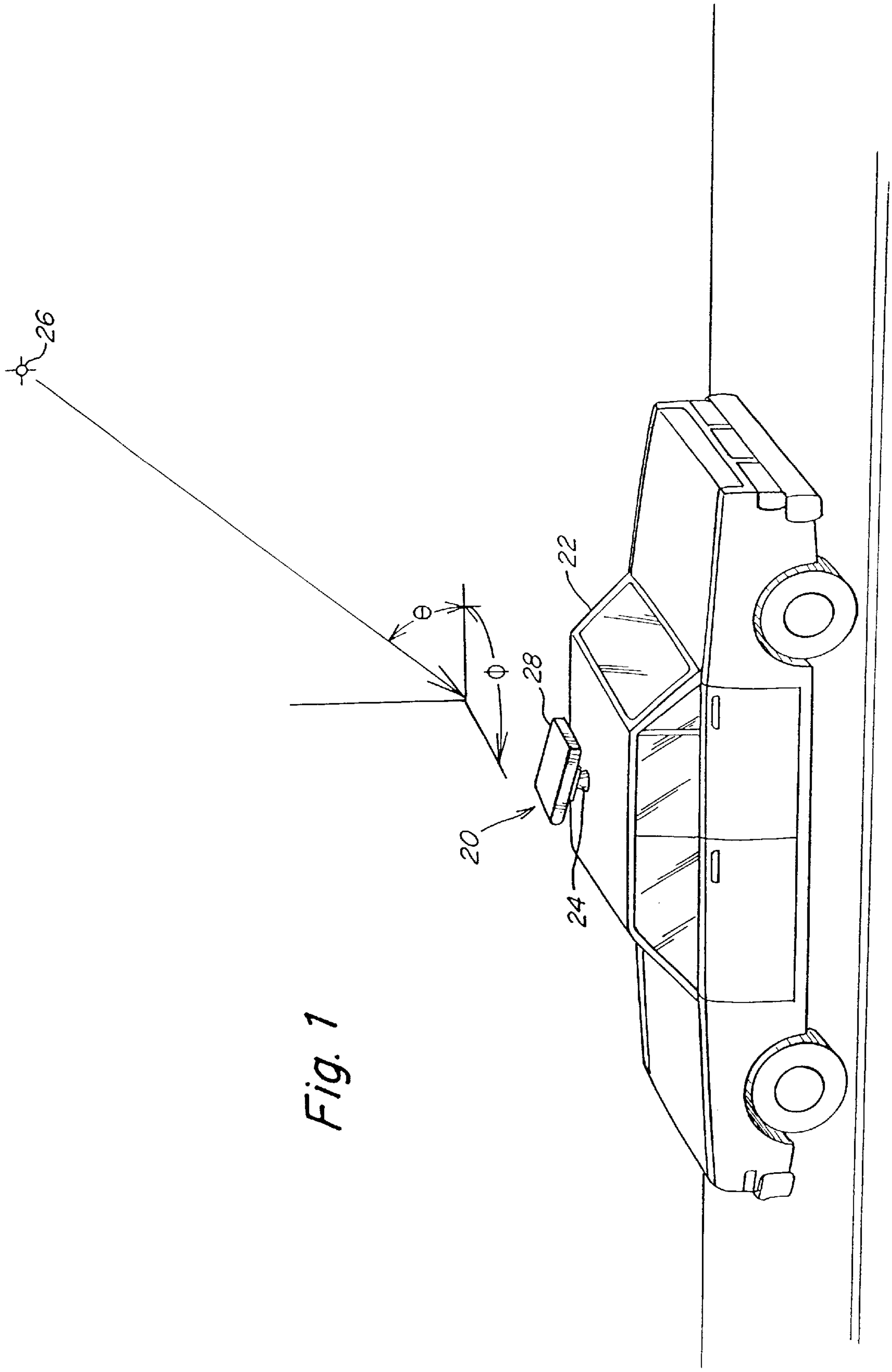

Fig. 1

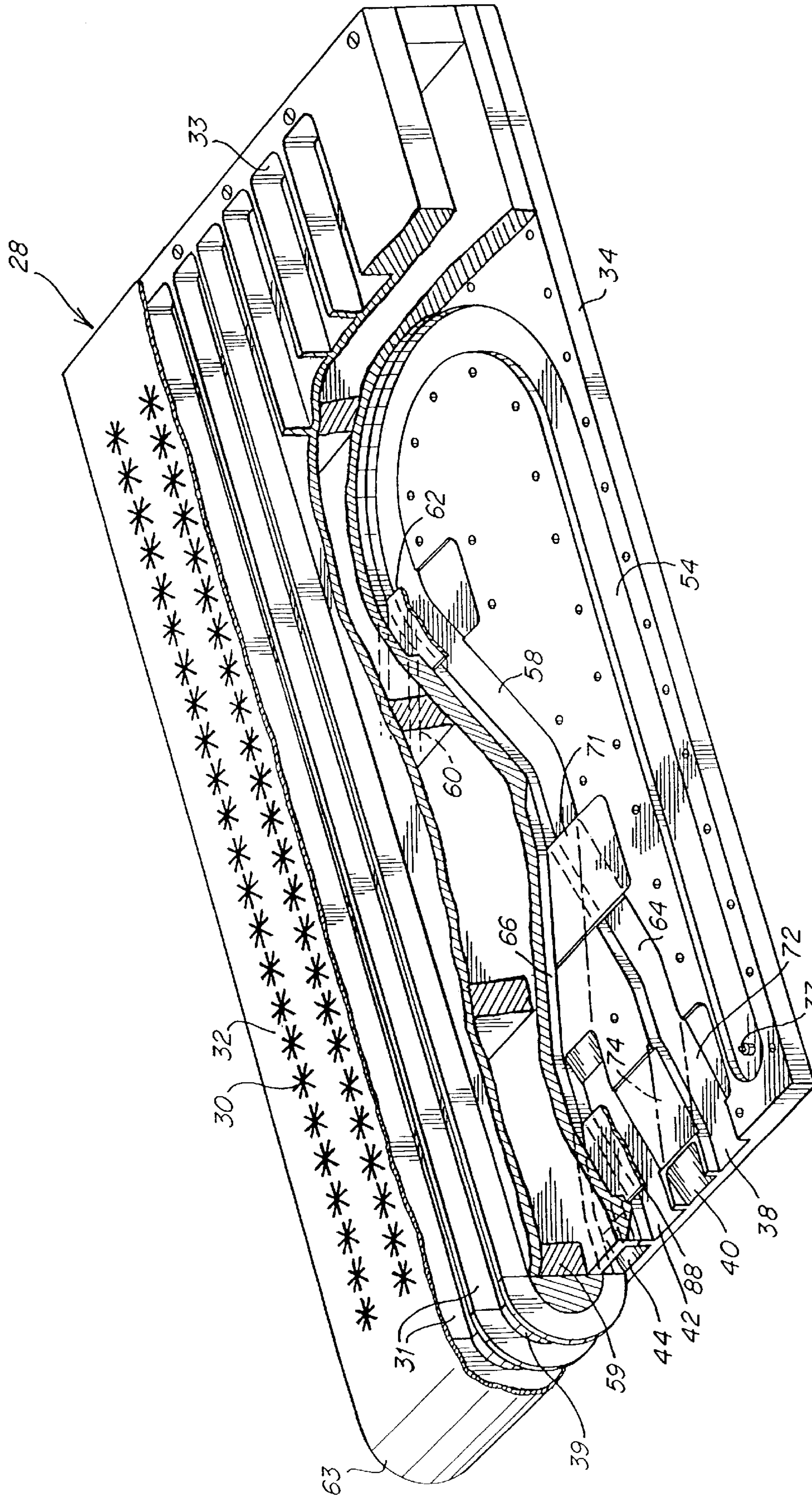

Fig 2

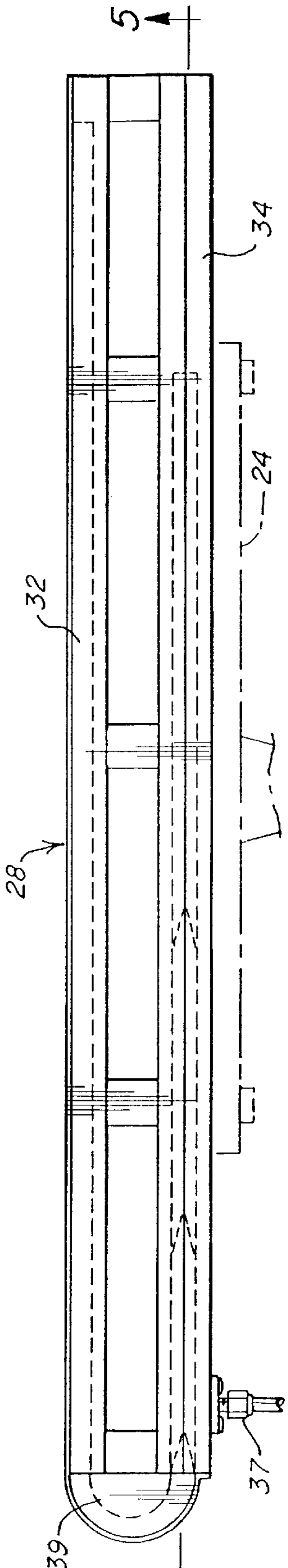

Fig. 3

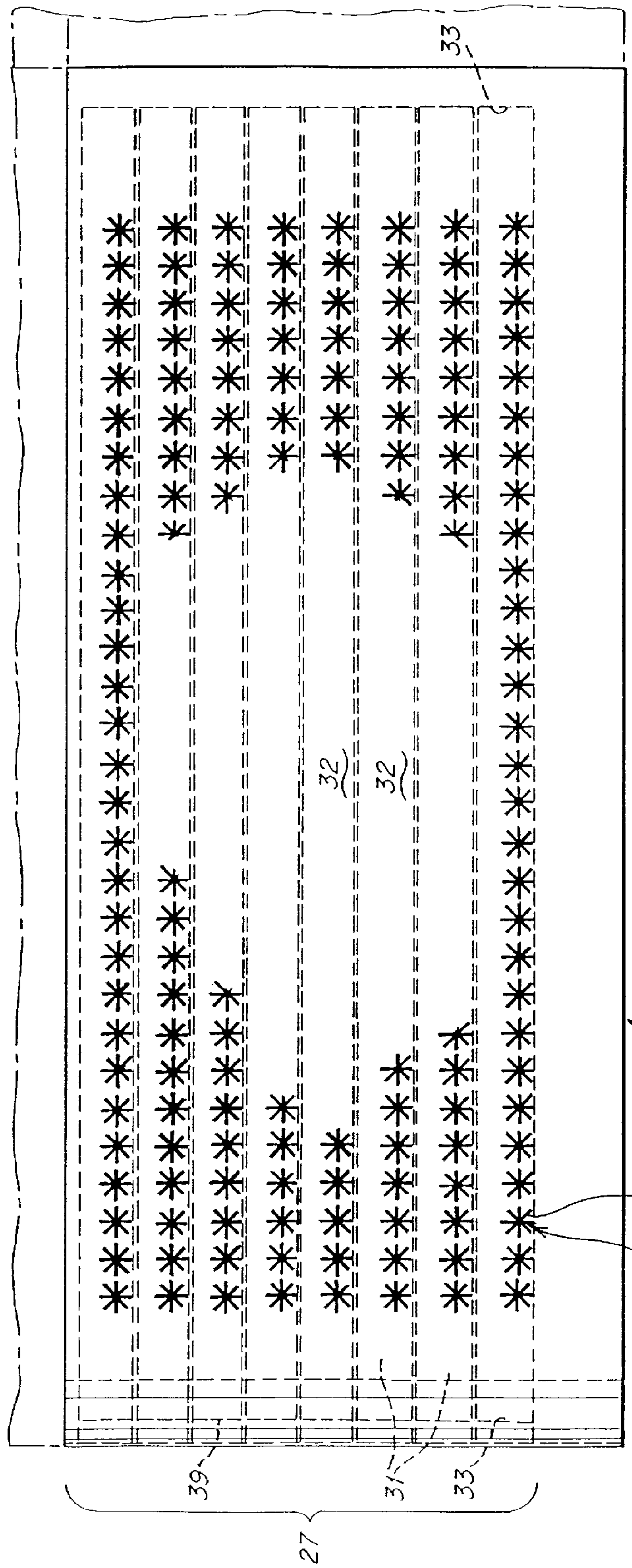

Fig. 4

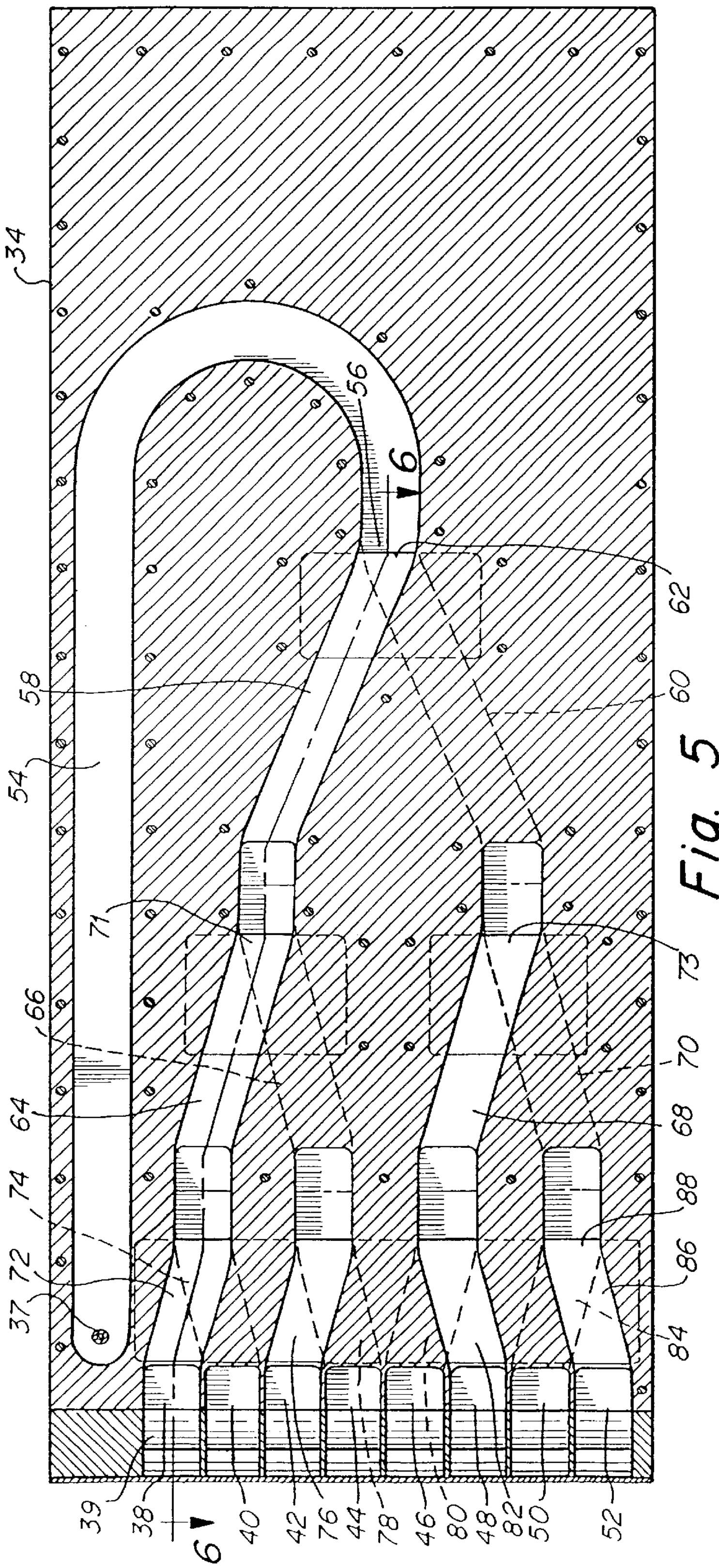

Fig. 5

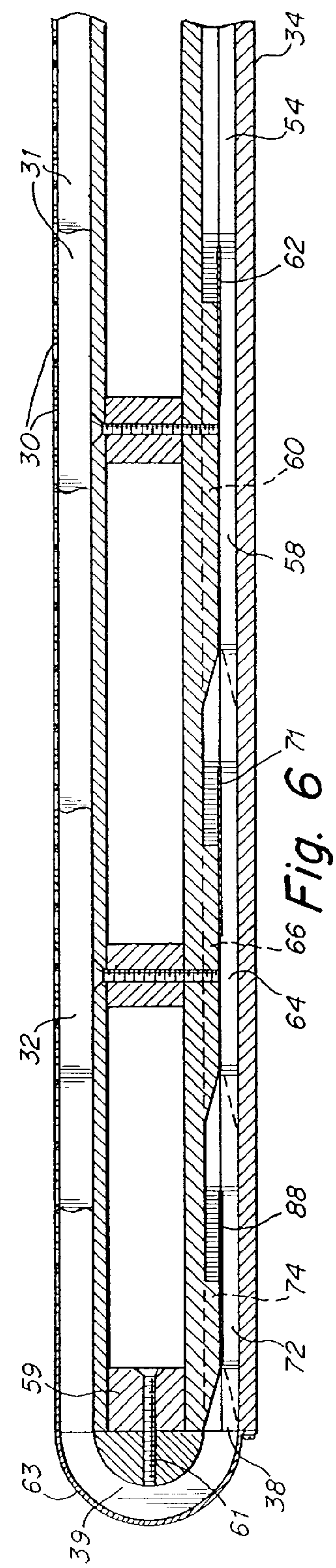

Fig. 6

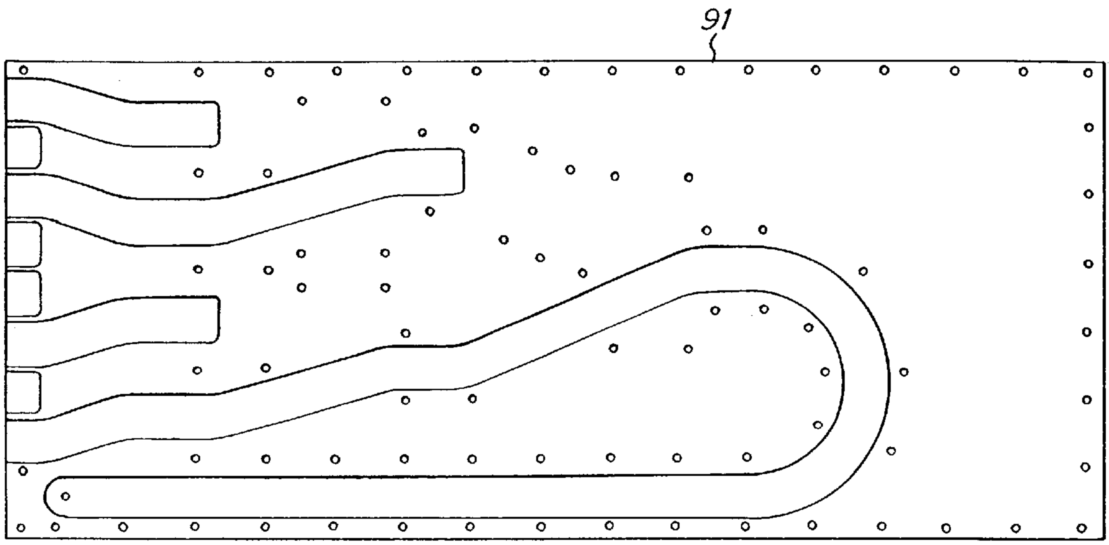

Fig. 7

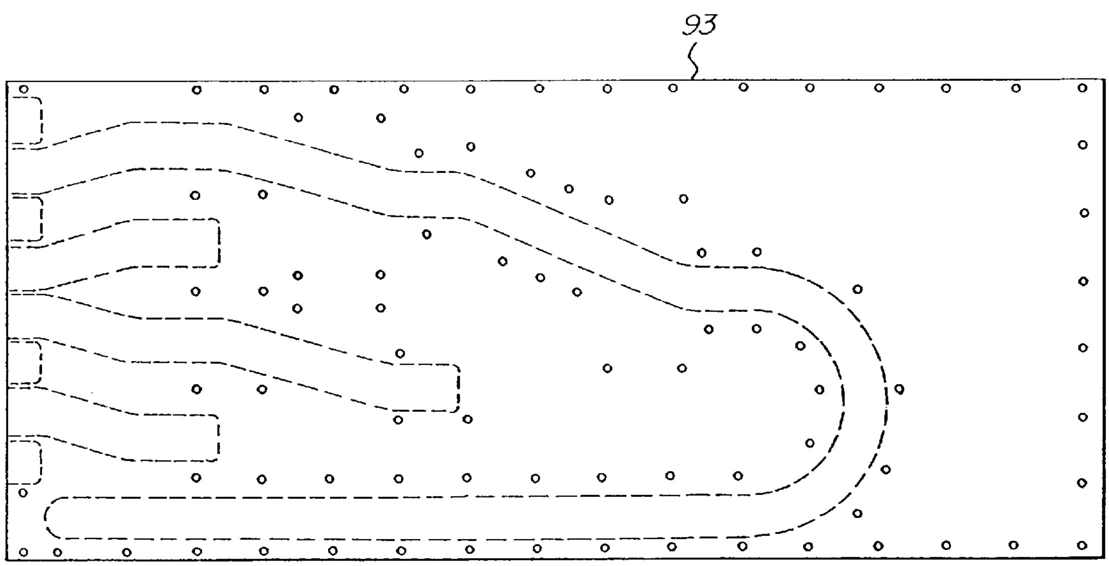

Fig. 8

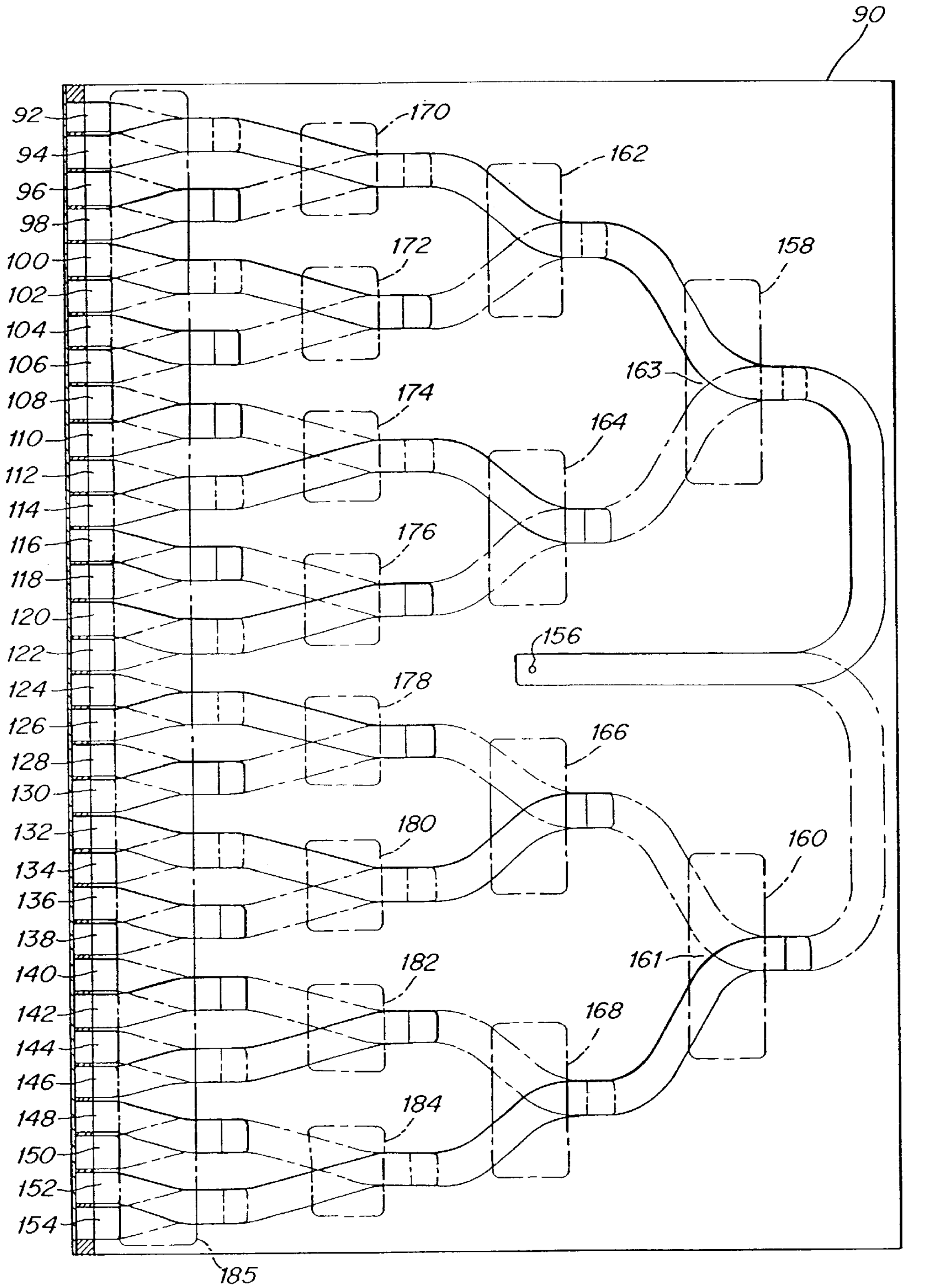
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Fig. 9

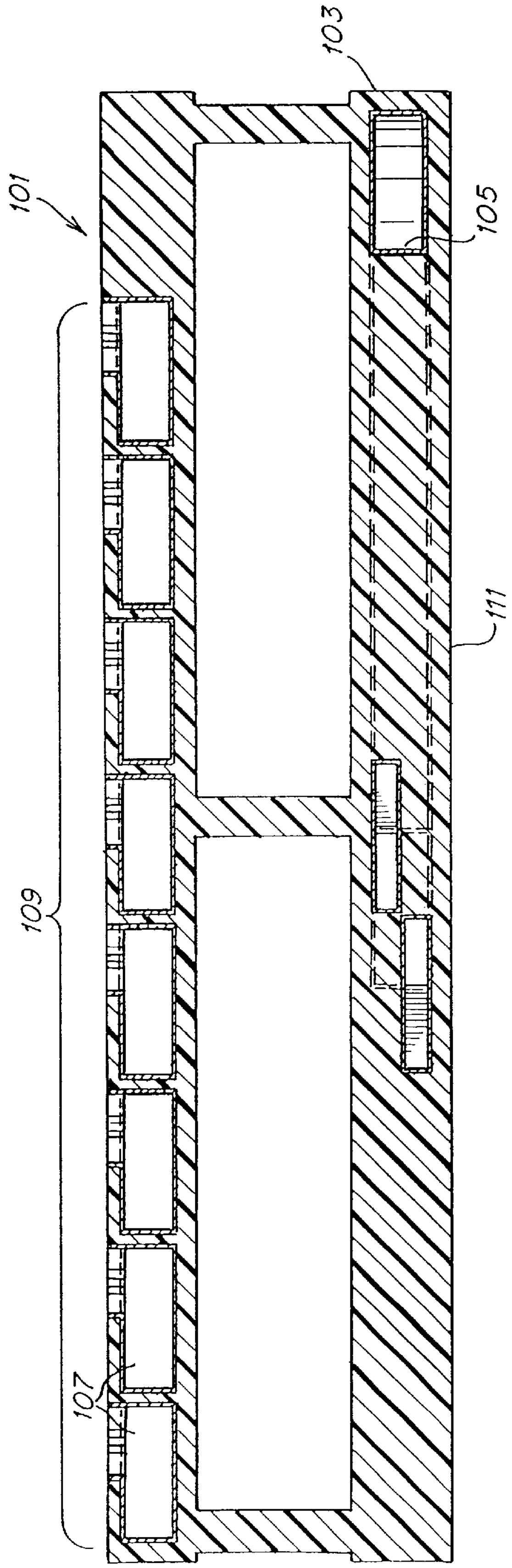

Fig. 10

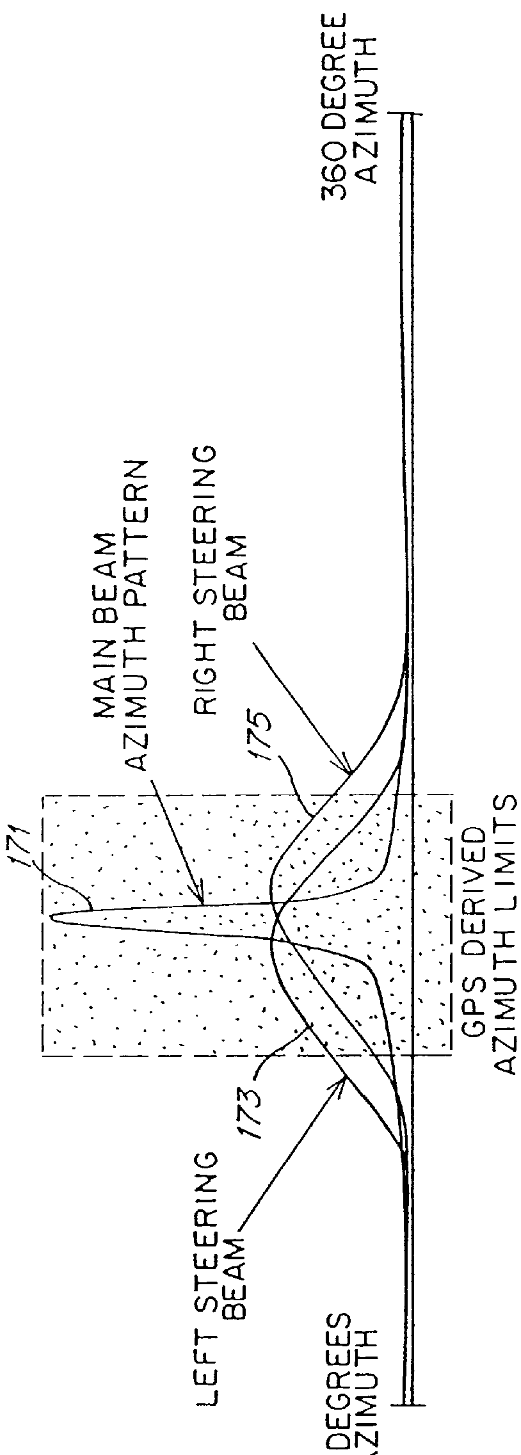

Fig. 11A

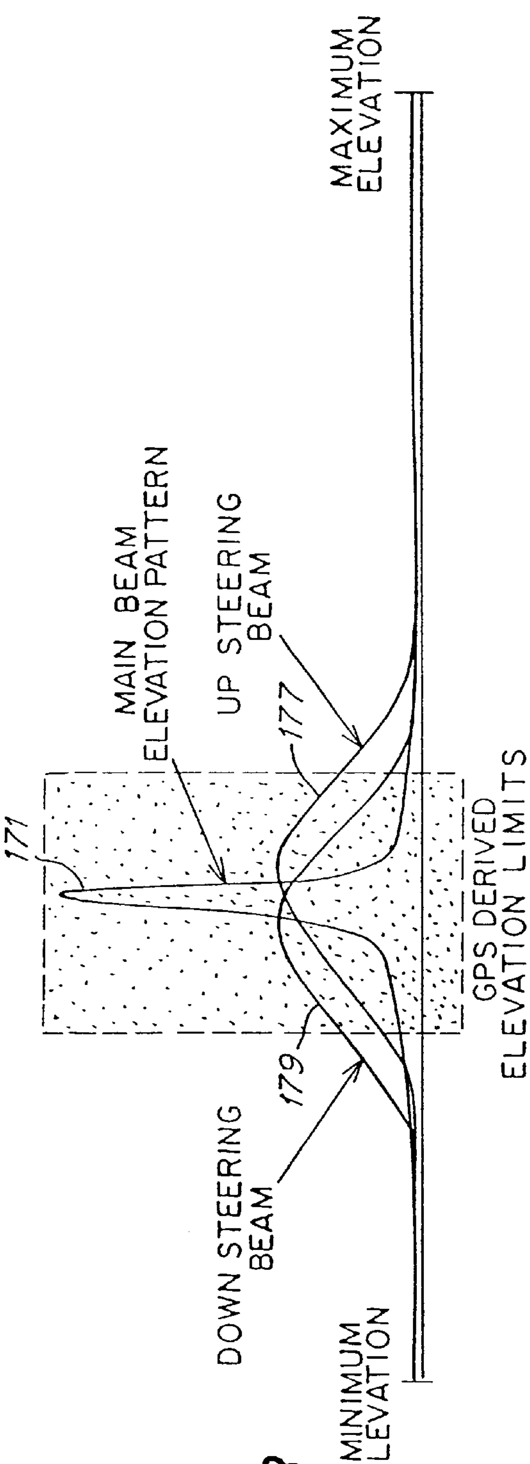

Fig. 11B

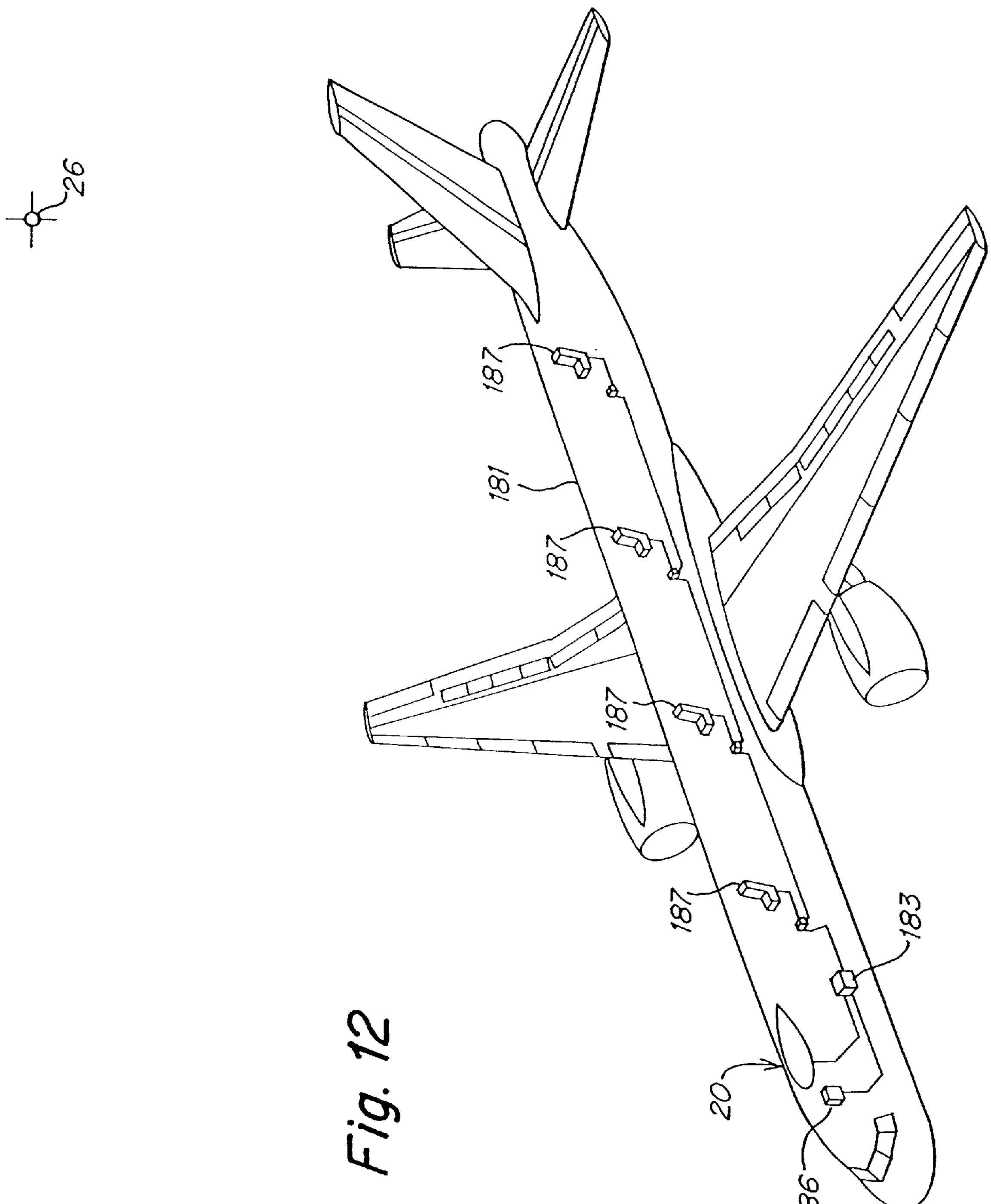

Fig. 12

LOW-HEIGHT, LOW-COST, HIGH-GAIN ANTENNA AND SYSTEM FOR MOBILE PLATFORMS

This application is a con of Ser. No. 08/932,190 Sep. 17, 1997 U.S. Pat. No. 5,973,647.

FIELD OF THE INVENTION

The present invention relates to a video entertainment system for passenger vehicles and, more particularly, to a low-height, low-cost, high-gain, leaky wave antenna system disposed in a low-drag radome and a system for providing satellite broadcasted video directly to passengers on mobile platforms such as, for example, airplanes, boats and automobiles.

BACKGROUND OF THE INVENTION

Various embodiments of antennas for reception of satellite broadcasted signals designed for mounting on vehicles have been studied and proposed. Since such an antenna is to be mounted, for example, on a roof or the like of an automotive vehicle running on a road where the height of the cars are legally restricted or, for example, on an aircraft where height is also an issue with respect to, for example, any drag associated with such an antenna that may result in decreased fuel efficiency, an important feature of such an antenna is to minimize a height of the antenna and an antenna mounting area. In addition, where the antenna is to receive at all possible times the satellite broadcasted signal and thus where the antenna at all times must be pointed in a direction of the satellite which will vary with time as the vehicle moves, it is important to have a tracking mechanism for controlling an azimuth and elevation angle of the antenna. However, the tracking mechanism can constitute a considerable part of the whole antenna manufacturing costs, complexity and height or mounting area of the antenna. Thus, it is important to minimize the space, complexity and requirements of the tracking mechanism and the antenna.

Disclosed, for example, in U.S. Pat. No. 5,579,019 (hereinafter the "'019 patent") is a slotted leaky waveguide array antenna for reception of satellite broadcast electromagnetic waves that may be mounted on a roof of an automobile. In particular, the '019 patent discloses a slotted leaky waveguide array antenna that enables reception of a direct broadcast satellite signal even with movement of the automobile, by providing an elevation beam width of about ±/−5° in the elevation direction which is disclosed to be wide enough so that no tracking system need be used to move the antenna in the elevation direction. Thus the tracking mechanism and antenna of the '019 patent has an economy of scale in that the antenna need only be rotated throughout 360° of the azimuth angle. The antenna of the '019 patent includes a plurality of waveguides disposed in parallel, wherein each waveguide has a plurality of slots disposed along the waveguide axis and having varying offset, length, and intersection angle values determined by a methodology. In addition, the reference discloses that the waveguide antenna array includes a feed waveguide for distributing electromagnetic waves to each of the plurality of waveguides which is disposed in a same plane as the array antenna and includes a first section extending along an end of each of the plurality of waveguides and a second section extending from a center of the antenna to a center of the first section which is perpendicular to the first section to thereby form a T-junction feed waveguide. The feed waveguide allows the antenna to be rotated in the horizontal or azimuth plane at a rotary

center of the antenna without subjecting a converter that is coupled to an output of the antenna to any rotation. An asserted advantage of the '019 patent is that the converter can be kept in a stationary position thereby reducing the stress on the converter and prolonging the life of the converter.

Another issue with the various slotted waveguide antennas that have been proposed are the costs, the ease of manufacture, and the weight of the various waveguide antennas. For example, a conventional slotted waveguide antenna may be manufactured combining metal plates with a proper precision suitable for a desired frequency range to form a plurality of waveguides, and then securing the waveguides to each other in a transverse direction in an array-like manner. Subsequently, or in conjunction, depending upon the position of a feed waveguide, the feed waveguide may then be secured to the waveguide array. However, such a manufacturing process may not be suitable for mass production and therefore such a slotted waveguide antenna array may not be provided inexpensively using such a method. Moreover, such an embodiment of the slotted waveguide antenna may require reinforcement to avoid movement of the waveguides within the waveguide array. Further, such an embodiment of a waveguide may be typically made out of a metallic material with a high specific gravity which is, for example, for aluminum approximately 2.7 and yields a heavy slotted waveguide antenna array. Thus, conventional slotted waveguide antenna arrays are typically bulky, heavy and not suitable for efficient and cost effective mass production.

U.S. Pat. No. 4,916,458 discloses an embodiment of a slotted waveguide antenna that is intended to be manufactured easily, inexpensively and that includes a plurality of radiating waveguides each having at least one radiating slot. The antenna also includes a feed waveguide disposed at one end of each of the plurality of waveguides for feeding the plurality of radiating waveguides and a plurality of apertures between the feed waveguide and the radiating waveguides. The plurality of waveguides and the feed waveguide are formed in a single plane by a dielectric plate that is sandwiched between conductive layers to form broad walls of the plurality of waveguides and the feed waveguide. In addition, either plated through-holes having a gap between each of the plated through-holes that is smaller than a wavelength of a signal propagating in the waveguides, or conductive pins having a similar gap therebetween and that are metalized on both sides, are inserted between the conductive layers and used to form the walls of the plurality of waveguides and the walls of the feed waveguide. In addition, the '458 patent discloses that outer peripheral walls of the plurality of waveguides and the feed waveguide can be provided by covering the dielectric plate material with a conductive material to form the outer peripheral walls. The slotted waveguide antenna of the '458 patent is asserted to be easy and inexpensive to manufacture and produce.

It is an object of the present invention to provide an improved leaky waveguide array antenna.

SUMMARY OF THE INVENTION

According to one embodiment of the present invention, a leaky waveguide antenna array that receives and/or transmits electromagnetic signals, includes a plurality of radiation waveguides disposed in parallel to each other to form the antenna array. A feed waveguide provides an electromagnetic signal to the plurality of radiation waveguides and/or receives a plurality of electromagnetic signals from the plurality of radiation waveguides and provides a composite electromagnetic signal at an output of the feed waveguide. Each of the plurality of radiation waveguides has a waveguide axis and includes a plurality of apertures arranged in a direction of the waveguide axis. The feed waveguide includes a first section of waveguide having a first end connected to an input/output port. The first section of waveguide has a height substantially the same as the height of each of the plurality of radiation waveguides and the first section of waveguide has a second end coupled to a first junction point. The first junction point transitions from the first section of waveguide to a second section of waveguide and a third section of waveguide that each have a height that is substantially half of the height of the first section of waveguide. The second section of waveguide transitions with an upward ramp to the substantially half height of the first section of waveguide. The third section of waveguide transitions with a downward sloping ramp to the substantially half height of the first section of waveguide. The third section of waveguide is substantially a mirror image of the second section of waveguide. The feed waveguide also includes a septum connected to vertical walls of the first, second and third sections of waveguide which aids in the transition from the height of the first section of the waveguide to the height of the second section and the third section of waveguide. Each of the second section of waveguide and the third section of waveguide are coupled to a corresponding first signal port and second signal port of the feed waveguide. Each of the first signal port and the second signal port are coupled to a corresponding one of the plurality of radiation waveguides.

With this arrangement, an antenna of reduced height and length can be constructed and mounted on a moving platform such as, for example, an automobile and that is part of a system to transmit and/or receive any of live video programming, images, interactive services, two-way communications and other data signals. In addition, the leaky waveguide antenna array and feed waveguide can be construed or molded from a composite material. With this arrangement, the antenna and feed waveguide can be manufactured more easily, reduced in weight as compared to, for example, an antenna assembled out of a metal such as aluminum, and can be provided at a lower cost.

According to another embodiment of the present invention, the leaky waveguide antenna and the feed waveguide can be mounted on an antenna positioning apparatus and disposed within a low-drag radome on a moving vehicle. With this arrangement, the antenna can be moved in both azimuth and elevation angles to keep the antenna pointed at, for example, a transmitting satellite providing broadcast video signal as the vehicle is moving. This embodiment can also be provided with at least one pair of steering arrays also mounted on the antenna positioning apparatus and disposed within the low-drag radome.

Another embodiment of the present invention is a method of providing a signal to passengers within a vehicle, wherein the vehicle is in an area where reception of the signal is not available. The method includes receiving the signal, with a first receiver in an area where the signal is available, and retransmitting the signal, received by the first receiver, to a second receiver that is located on a vehicle that is not within the area where the signal is available. The method further includes the steps of retransmitting the signal received by the second receiver to a third receiver located on a vehicle that is within the area where the signal is not available. The method further comprising the step of repeating the step of retransmitting the received signal to any vehicle which is in the area where the coverage is not available so that each of the vehicles can receive the signal and present it to passengers within each of the vehicles.

With this arrangement, any of live video programming, images, interactive services such as the internet, two-way communications such as telephone communication and other data signals can be provided to passengers within vehicles even though the vehicles are not within an area where the signal can be received due to, for example, a lack of satellite coverage, or non-continuous satellite coverage, or a lack of ground to air communications facilities, or a poor signal quality. This is particularly advantageous for aircraft flight paths such as, for example, transoceanic flights where a plurality of airplanes are lined up in a path traversing an ocean and where satellite coverage is not yet available above the ocean.

Other objects and features of the present invention will become apparent from the following detailed description when taken in connection with the following drawings. It is to be understood that the drawings are for the purpose of illustration only and are not intended as a definition of the limits of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects and advantages will be more fully appreciated from the following drawing in which:

FIG. **1** is a perspective view of an antenna subsystem of the present invention mounted on a roof of an automobile;

FIG. **2** is a perspective view partially broken away of an antenna of the antenna subsystem of FIG. **1**;

FIG. **3** is a side elevational view of the antenna of FIG. **2**;

FIG. **4** is a top plan view of the antenna of FIG. **2**;

FIG. **5** is a cross-sectional bottom plan view of an embodiment of a waveguide feed of the antenna, taken along line **5**—**5** of FIG. **3**;

FIG. **6** is a cross-sectional side view of the antenna, taken along line **6**—**6** of FIG. **5**;

FIG. **7** is a plan view of one half of a waveguide feed of the antenna of FIG. **2**;

FIG. **8** is a plan view of a second top half of the waveguide feed of FIG. **7**;

FIG. **9** is a cross-sectional bottom plan view of an alternate embodiment of a waveguide feed assembly for the antenna of the present invention;

FIG. **10** is a cross-sectional end view of an extruded embodiment of the antenna of the present invention;

FIG. **11** is a plot illustrating a beam pattern of the antenna of the present invention including a main antenna beam and a plurality of steering array antenna beams; and

FIG. **12** is a perspective view of the antenna subsystem of the present invention mounted to the fuselage of an aircraft.

DETAILED DESCRIPTION

The antenna and system of the present invention provide, for example, any of live broadcast television programming, two-way communications signals, interactive service signals such as internet service, and other forms of data signals directly to passengers on mobile platforms such as, for example, airplanes, boats and automobiles. In a preferred embodiment, the antenna and system is to be used with existing digital satellite broadcasting satellites and technology to provide live broadcast television programming to the passengers. For example, in the preferred embodiment of the antenna and system of the invention, passengers in a vehicle can select and view live news channels, weather information, sporting events, network programming, and movies similar to programming that is available in most homes either through cable or satellite services. One advantage of the preferred embodiment of the antenna and system of the present invention is that the programming is live with no need for video-tape duplication and distribution, and since no tapes are required, all equipment can be located in a storage area of the passenger vehicle thereby not consuming any passenger space.

A single antenna on a vehicle may support generation of any of the signals discussed above for all passengers in the vehicle. Referring to FIG. **1**, one embodiment of the antenna subsystem **20** is a low-height, low-cost, high-gain, leaky wave array antenna **28** that may be disposed in a low-drag radome (not illustrated) and may be mounted for example, to a roof top of the automobile **22**. The antenna subsystem may include antenna positioning apparatus **24** such as, for example a motor driven gimble system, so that the antenna may be move 360° in azimuth (ϕ) and, for example, over a range of approximately 50° in elevation (θ). The low-drag radome preferably will taper to the vehicle and allow movement of the antenna positioning apparatus and antenna in both azimuth and elevation.

In one embodiment of the antenna subsystem of the present invention, a beam pattern of the antenna **28** may have a beam width in azimuth of approximately 4° to 5° which may be scanned in the azimuth plane by physical movement of the antenna array over 360° in azimuth. In addition, the beam pattern of the antenna may have a beam width in the elevation plane of approximately 4° to 8° which may be scanned in the elevation plane by physical movement of the antenna array over approximately a 50° elevation sector such as, for example, over an elevation angle range between 20° to 70°. The antenna subsystem **20** of the present invention will track the location of a transmitting satellite **26** with respect to the position and orientation of the moving vehicle and will point the antenna beam towards the transmitting satellite.

FIG. **2** is a perspective, partially broken away view of one embodiment of the antenna **28** of the present invention; FIG. **3** is a side elevational view of the antenna of FIG. **2** and FIG. **4** is a top plan view of the antenna of FIG. **2**. Referring to FIGS. **2** and **4**, the antenna **28** of the present invention may include an array **27** of substantially rectangular waveguides **31**, wherein each substantially rectangular waveguide may include one or more apertures **30** in a broad (H-plane) wall **32** of the substantially rectangular waveguide. It is to be appreciated that any aperture can be used that will transmit and/or receive electromagnetic energy in a desired polarization such as, for example, a circular polarization. In a preferred embodiment, the apertures are asterisk-shaped aperture elements in the broad wall of the waveguide that can be formed, for example, by forming a first crossed slot element and then forming a second crossed slot element rotated by 45° from the first cross element in the broad wall of the waveguide. The legs **36** of the asterisk-shaped element slightly reduce the elements' sensitivity to amplitude of a transmitted and/or receive electromagnetic signal. In addition, it is easier to empirically determine a desired configuration of the antenna elements to provide a desired amplitude and axial ratio of the antenna using the asterisk-shaped antenna elements.

The substantially rectangular waveguides **31** are oriented so that narrow walls of the waveguides are disposed in parallel to each other and the broad (H-plane) walls **32** including the apertures **30** form the array of antenna elements. The apertures are preferably spaced apart at a half of a wavelength of an operating frequency along a length or the axis of the substantially rectangular waveguide and preferably transmit and/or receive electromagnetic energy at a 45° elevation angle referenced to either the plane of the antenna array (horizontal) or a normal to the antenna array (vertical). Each of the rectangular waveguides is fed at one end **33** by a waveguide feed **34** and is terminated at a second end **33** by a non-reflecting match load (not illustrated).

Referring now to FIG. **5**, there is illustrated a cross-sectional bottom plan view of the waveguide feed **34** taken along line **5**—**5** of the antenna **28** illustrated in FIG. **3**. As discussed above, the antenna and waveguide feed can be used to transmit and/or receive electromagnetic energy. In a preferred embodiment, the antenna and waveguide feed are use to transmit and/or receive satellite broadcast signals for digital video programming. Operation of the antenna will now be described for the case when the antenna is to transmit electromagnetic energy. The electromagnetic energy is fed to each substantially rectangular waveguide **31** (See FIG. **4**) via the waveguide feed **34**. In particular, an electromagnetic signal is provided to the waveguide feed at an input/output port **37** and the signal is equally divided both in phase and in amplitude by the waveguide feed to provide an equal amplitude and phase signal at each of signal ports **38**, **40**, **42**, **44**, **46**, **48**, **50** and **52**. As will be discussed in greater detail below, the electromagnetic signals at each of ports **38**–**52** are preferably provided to each of the substantially rectangular waveguides **31** by a corresponding E-plane bend **39** as illustrated in FIG. **3**. The electromagnetic signal is induced in the waveguide feed at port **37**, propagates through the waveguide feed and is fed to each of the substantially rectangular waveguides, and is preferably in a TE_{10} dominant mode of the electromagnetic signal. The TE_{10} dominant mode of the electromagnetic signal propagates along the length or axis of each substantially rectangular waveguide to feed each aperture **30** in the broad (H-plane) wall **32** of each substantially rectangular waveguide so as to radiate the circularly polarized antenna pattern at the desired elevation angle θ, as discussed above.

Operation of the antenna **28** and the waveguide feed **34** when the antenna is to receive an electromagnetic signal such as a digital satellite broadcast signal is opposite to that discussed above for transmitting an electromagnetic signal. In particular, each of the apertures **30** in the broad wall **32** of each substantially rectangular waveguide **31** receives a circularly polarized electromagnetic signal and induces a TE_{10} dominant mode of the electromagnetic signal within each substantially rectangular waveguide. The dominant mode of the electromagnetic signal propagates along the length or axis of the substantially rectangular waveguide to the end **33** of the substantially rectangular waveguide and is coupled to a corresponding signal port **38**–**52** of the waveguide feed **34** by a respective E-plane bend **39**. The electromagnetic signal at each of signal ports **38**–**52** is then combined or summed via the waveguide feed to provide a combined or summed signal at the input/output port **37** of the waveguide feed.

FIG. **6** illustrates a cross-sectional side view of the waveguide feed **34** taken along line **6**—**6** of the feed as illustrated in FIG. **5**. The plurality of E-plane bends **39** allow the waveguide feed **34** to be located under the antenna array, thus reducing a total length of the antenna **28**. The E-plane bends couple each substantially rectangular waveguide **31** to a corresponding port **38**–**52** of the waveguide feed and include a curved section **39** of an acceptable bend radii as known to those of skill in the art. For example, a reference by Theodore Moreno, *Microwave Transition Design Data*, McGraw-Hill, 1948 provides specific recommendations for the use of E-plane bends with waveguides. Each of the E-plane bends can be secured to a spacer **158** between the antenna array **27** and the waveguide feed **34** by a corresponding screw **160**. In addition, each of the E-plane bends can be sealed with an end-cap **162**. It is to be appreciated that although the antenna array and the feed waveguide have been described and illustrated in two different planes, in particular, with the feed waveguide disposed below the antenna array, the feed waveguide and the antenna array may be in a same plane; for example the antenna array of waveguide may be coupled to the corresponding signal ports of the feed waveguide by a plurality of the H-plane bends or waveguide sections.

It is to be appreciated that although the waveguide antenna and waveguide feed have been described for a single polarized signal, that other embodiments are contemplated to be within the scope of the present invention. For example, each waveguide of the plurality of radiation waveguides may have two parallel rows of a plurality of apertures disposed along the axis of the waveguide wherein one row of apertures may be at a left side of a center axis of the broad wall and is used to transmit and/or receive a left hand circularly polarized signal and a second row of apertures may be at a right of the center axis of the broad wall and may be used to transmit and/or receive a right hand circularly polarized signal. For this embodiment, each of the left hand circularly polarized signal and the right hand circularly polarized signal may be fed and/or may provide the signal at one end of the waveguide and therefore only a single waveguide feed need be used to transmit and/or receive the left hand and right hand circularly polarized signals. In particular, a switching device such as, for example, a PIN diode may be used to switch between the left hand circularly polarized signal and the right hand circularly polarized signal to provide and/or receive the signal at the end of the waveguide. The switching device may be disposed, for example, at the end of each radiation waveguide where it is coupled to the waveguide feed.

Referring to FIG. **5**, the waveguide feed includes a first section of waveguide **54** that has a full height for a waveguide operating at a particular wavelength or frequency and in the TE_{10} mode. In other words, the height of the first section of waveguide is substantially the same as the height of the waveguides **31** of the antenna **28**. At a first junction point **56**, the first section of waveguide **54** is divided into a pair of half-height waveguide sections **58, 60**. A second section **58** of waveguide is transitioned to a height that is substantially half of the height of the first section of waveguide by a downward ramp in the height of the waveguide, while a third section **60** of waveguide is transitioned to the half-height by an upward ramp in the height of the waveguide. In addition, a septum **62** is provided at the first junction point **56** to aid in the transition from a full height waveguide section to the pair of half-height waveguide sections. The septum is preferably substantially or infinitely thin such as, for example, on the order of 0.006" thick, is conductive and contacts the narrow walls of the waveguide sections **56, 58** and **60** to aid in alignment of the full height to half-height transition.

In a similar manner, each of the half-height waveguide sections **58** and **60** is divided into a first pair **64, 66** and a second pair **68, 70** of corresponding half-height waveguide sections. It is to be appreciated that waveguide sections **58, 60; 64, 66** and **68, 70** are mirror images of each other or, in other words, each of waveguide sections **58, 64, 68** has a decline or downwardly disposed ramp to form a half-height waveguide element and each of waveguide sections **60, 66, 70** has an incline or upwardly disposed ramp to form a half-height waveguide element of substantially equal length to waveguide element **58, 64, 68**. In addition, corresponding septums **72** and **74** are provided at a second junction points between the second section of waveguide, the third section of waveguide and waveguide sections **64,66**, and **68, 70** to aid in the transition from one half-height waveguide element to two half-height waveguide elements. The waveguide elements **64, 66** and **68, 70** are mirror images of each other. It is to be appreciated that in a similar manner, each of waveguide sections **64, 66, 68** and **70** are transitioned from a single half-height waveguide section to a pair of corresponding half-height waveguide sections **72, 74; 76, 78; 80, 82**; and **84, 86** which are coupled to each of the corresponding signal ports **38, 40, 42, 44, 46, 48, 50** and **52**. A septum **88** aids in each transition from a single half-height waveguide section to two half-height waveguide sections. Each of the waveguide elements **72, 74; 76, 78; 80, 82**; and **84, 86** are mirror images of each other. It is the combination of the full height and the pairs of half-height waveguide sections that are mirror imaged with inclining and declining ramps as well as the septums that make up a 1-to-8 element waveguide feed illustrated in FIG. **5**.

Referring to FIGS. **7–8** which are plan views of an embodiment of a waveguide feed **34**, it is to be appreciated that the waveguide feed **34** can be formed as two plates **91, 93** that are mirror images of each other such as illustrated in FIGS. **7–8**. In addition, it is to be appreciated that since each path from the input/output port **37** of the waveguide feed to the signal ports **38–52** is identical and because each path has a mirror-image orientation, the waveguide feed operates to add the electromagnetic signals received at ports **38–52** from the antenna **28** and to provide the summed signal at input/output port **37** or to divide an electromagnetic signal provided at input/output port **37** to provide a equally divided signal both in amplitude and phase at ports **38–52**.

It is to be appreciated that although the discussion above has been directed to an antenna array including eight waveguides and an 1-to-8 waveguide feed **34** as illustrated in FIGS. **4–8**, the waveguide feed **34** and waveguide antenna **28** of the present invention can be made up of any of 2, 4, 8, 16, 32, 64, 128 and the like waveguides forming the antenna array and a corresponding 1-to-2, 1-to-4, 1-to-8, 1-to-16, 1-to-32, 1-to-64, 1-to-128 and the like waveguide feed. For example, FIG. **9** illustrates a schematic view of an alternative embodiment of a waveguide feed **90** according to the present invention. The waveguide feed **90** is a 1-to-32 element waveguide feed that operates in a manner similar to the 1-to-8 waveguide feed **34** discussed above, to either add signals received from thirty two corresponding waveguides of an antenna array at ports **92, 94, 96, 98, 100, 102, 104, 106, 108, 110, 112, 114, 116, 118, 120, 122, 124, 126, 128, 130, 132, 134, 136, 138, 140, 142, 144, 146, 148, 150, 152**, and **154** and provide a summed signal at input/output port **156** or to divide an electromagnetic signal at input/output port **156** and to provide an equal amplitude and phase signal at each of signal ports **92–154**. The waveguide feed **90** may have a plurality of septums **158, 160, 162, 164, 166, 168, 170,172, 174, 176, 178, 180, 182** and **184** to aid in the corresponding transitions from a full height waveguide to two half-height waveguides that occur at transition points **161, 163** or to transition from a single half-height waveguide to two half-height waveguides at septums **162–184**. It is to be appreciated that each of the waveguide sections will be a mirror image of an adjacent waveguide section of a pair of waveguide sections wherein if one waveguide section has an incline in height an adjacent waveguide element will have a decline in height to provide the half-height waveguide.

It is to be appreciated that the antenna **28** according to the present invention can be used on any of a number of mobile platforms and should have a high-gain, a small size, and a good cross-polarization rejection for successful reception of digital satellite broadcasting video signals. Additionally, it is to be appreciated that for aircraft and many other moving platforms, the antenna should be low in height and reduced in length to minimize any drag provided by the antenna and to maintain the esthetics of the mobile platform. It is known that any residual drag of the antenna and radome on a moving vehicle such as an aircraft and fast moving ground vehicles, including automobiles, increases the fuel costs of operating the moving vehicles. Over the life of the vehicle the supplemental fuel costs associated with the drag of the radome and the antenna can equal or exceed the cost of the antenna system. A low-height radome with a proper curved outer surface (camber) can greatly reduce a parasitic drag caused by air flowing over the radome. This is why contemporary automobiles or moving platforms are frequently designed and tested in wind tunnels to reduce the parasitic drag of the vehicles.

Thus, the parasitic drag is of primary importance to an antenna system to be used on a moving vehicle. Accordingly, a low-height (and low-drag), low-cost antenna system is needed. In addition, the expense of the radome depends, for example, on transmissivity requirements such as refraction, absorption, and reflection to, for example, a circularly polarized signal to maintain the quality signal and the constituent materials of the radome, as well as the total volume of the radome materials. Thus, a low-height antenna and radome also reduces the volume and materials cost associated with the radome and thus the expense of the radome. In addition, as is known to those of skill in the art, an antenna with a long horizontal dimension has a narrow beam width in azimuth which complicates continued tracking of the transmitting satellite **26** (see FIG. **1**) since the antenna must be moved to keep the satellite within the antenna beam width. As is known to those of skill in the art a maximum theoretical gain of an antenna is determined by a subtended area of the antenna array projected in the direction of the satellite and can be described by Equation (1):

$$G=4\pi A/\lambda^2 \quad (1)$$

where G is the gain of the antenna, A is the subtended area of the antenna and λ is a wavelength of an operating frequency of the antenna. A typical gain of approximately 34 dB is needed for reception of direct broadcast satellite video for the continental United States. This gain results in an effective area of the antenna at a mid-band of the operating frequency range, which is typically 12.2 to 12.7 GHZ in the United States and South America or 11.7 to 12.2 GHZ in Europe, of approximately two hundred and eighty eight square inches. One embodiment of the present invention is a thirty-two waveguide element array having a width of approximately twenty-four inches in the azimuth plane; the array thus will have a length of approximately twelve inches. A height of a top of the array above the mobile platform surface is established by the array length and by a lowest elevation angle θ at which the antenna will be pointed such as, for example, 20°. For an array with a beam pattern that is perpendicular to the plane of the array, the height is determined by Equation (2):

$$H=L\cos(\theta) \quad (2)$$

where H is the height of the antenna L is the length of the antenna and θ equals the elevation angle. Thus, for the above-described antenna array, the height is approximately 11.3". However, as discussed above, according to a preferred embodiment of the antenna it is desired to offset the antenna beam pattern in the elevation direction from the perpendicular of the array. In order to maintain the same effective area of the antenna, the length of the antenna array increases by 1/cos (offset angle); but the overall height above the vehicle decreases by the relationship of Equation (3):

$$H=L\cos(\theta+\text{offset angle})/\cos(\text{offset angle}) \quad (3)$$

Thus, for the preferred embodiment of the thirty-two waveguide element antenna of the present invention having a 45° offset angle and a minimum elevation angle of 20°, the array length of 12" will increase to 17" while the height of the antenna will be reduced from approximately 11.3" to approximately 7.2". Thus, according to the preferred embodiment of the invention the peak of the main beam is offset from the perpendicular to the array to minimize height of the array when the antenna array is operated at low elevation angles off of the horizon. One advantage is that this also reduces the required radome size and any drag due to air resistance of the antenna and radome.

As discussed above, it may be desirable to reduce a complexity of and height of the tracking mechanism of the antenna by, for example, reducing the need to scan the antenna in elevation angle. This can be accomplished, for example, by providing the waveguide feed of the present invention with a plurality of phase shifters disposed within the waveguide feed at, for example, each junction point where there is a single waveguide to two waveguide transition. The plurality of phase shifters can be used to electronically steer the beam pattern in the elevation angle over, for example, the 50° elevation range from approximately 20° to 70°. The phase shifters may be, for example, waveguide mounted phase shifters that are any of electrical, electromechanical or even mechanical as are known to those of skill in the art. An alternative embodiment that may also be used to scan the antenna in elevation angle may be to form the narrow waveguide walls (E-plane walls) of the plurality of radiation waveguides so that they are dynamically variable and so that a spacing between the narrow walls can be varied to change the elevation angle of the antenna beam pattern. For example, when it is desired to scan the antenna in elevation angle, a mechanism such as, for example, a motor may be used to cause the dynamically variable waveguide walls to be increased or decreased in the vertical direction to scan the antenna beam and elevation angle. Some examples of waveguide walls that may be dynamically variable so as to change the spacing between the waveguide walls can be any of a continuous, corrugated, serrated, or folded walls such as, for example, diamond-shaped waveguide walls that provide vertical flexibility in the waveguide walls. The vertical flexibility may allow the sidewalls to be moved in and out of compression to vary the spacing between the narrow walls to scan the antenna in elevation angle. It is to be appreciated that for any embodiment where the waveguide walls and the spacing between the waveguide walls are to be variable, the narrow walls must still allow for contact between the narrow wall and the broad walls of the waveguide. These contacts may be accomplished for example by any of rivets, eyelets, or other fastener devices that may be used to align one section of the waveguide with corresponding through holes in another section of the waveguide so as to allow movement of the sections with respect to each other while maintaining the desired electrical contact.

Another embodiment of the antenna subsystem of the invention may include 2 arrays such as, for example, two 32-waveguide element arrays each having a respective offset angle of, for example, 35° and 65°. An advantage of this embodiment is that each respective waveguide array need only be physically or electrically steered over, for example, a 30° elevation angle range, in particular the array having an offset angle of 35° will be scanned or moved in elevation angle from 20° to 50°, while the array having the offset angle of 65° will be scanned or moved in elevation angle from 50° to 80°. An advantage of this embodiment is that since each array need only be steered over a 30° range in elevation angle, the overall height of the antenna and tracking system can be reduced.

In addition to having a low-height and short length it is also desirable that the antenna of the present invention have low manufacturing costs, a low-weight, be simple to manufacture and be able to operate in an environment of extreme temperatures, density, altitude, shock, vibration and humidity that is common to many mobile vehicles. Each of these objects can be obtained according to the present invention by an antenna structure that is made of advanced composites. For example, one embodiment **101** of the present invention as illustrated in cross-section in FIG. **10**, includes a cast structure **103** of a base composite material that is plated with a metal plating **105** to provide an antenna array **109** of waveguides **107** and a waveguide feed **111**. In a preferred embodiment of the antenna, the antenna is molded without ends of the waveguide and so that each aperture (not illustrated) within each broad wall of each substantially rectangular waveguide of the waveguide array is formed as part of an injection molding process to form the waveguide array and waveguide feed structure. An advantage of this process is that it has reduced tooling costs and is feasible to mold. It is to be appreciated however that other molding processes such as, for example, compression molding of sheet molding compounds can also be used to inexpensively produce an antenna array in one or more parts. Each of the molding tools and processes to produce the array are known and can be used to form the antenna array and waveguide feed to the net desired dimensions.

Once the base material has been molded into either unitary or piece parts of antenna array and waveguide feed, the antenna array and waveguide feed can then be plated using known forms of plating such as, for example, electroless or electrolytic plating processes. In addition, it is to be appreciated that in some instances application of an additional base material may be used to improve adhesion of a metallic coating to the base material. It should also be appreciated that sometimes a combination of electroless and electrolytic platings may be used. The plating is used to form a conductive shell internal, and if desired, external to the waveguide and the waveguide feed.

In one embodiment of the antenna **101** according to the present invention, preformed metal slots can be inserted into the molded base material to from the apertures (not illustrated) within each broad wall of each waveguide **107** to reduce complexity and precision requirements of the molding tool and of the plating process. In addition, it is to be appreciated that when using such inserts, it may not be necessary to plate the through-holes in the base material that provide the slots where the inserts are inserted. One method of inserting the inserts may be to use ultrasonic insertion which provides fast and economical anchoring of metal inserts and also provides a high degree of mechanical reliability with excellent pull-out and torque retention. Another advantage of ultrasonic insertion is that it results in lower residual stresses compared to other methods of insertion, because it insures a uniform melt and minimal thermal shrinkage. Another advantage of inserting preformed metal slots into the molded base material is that it results in reduced handling costs, especially if the cycle time of the molded part allows for secondary operations to be performed by the injection molding machine operator.

It is to be appreciated that selection of a base material is important to the design and construction of the antenna array and waveguide feed, to the plating of the base material and to providing inserts, if any, since each of the base material, the plating and the inserts may have different coefficients of thermal expansion thereby inducing stresses within the antenna and waveguide feed structure. Similar stresses may also include those due to the environment in which the antenna is to be operated such as shock, vibration, as well as humidity. All these factors influence the determination of the base material and the conductive coating. For example, on an aircraft, an extremely low-density, high-strength, dimensionally-stable material with low water absorption is desired. In a preferred embodiment, the antenna array and waveguide feed are molded from ULTEM®, which is a polyetherimide and is a registered trademark of GE. However, it is to be appreciated that other candidate materials include fibrous composite or reinforced resins, as well as a polyester resin. Each has a specific gravity in a range of 1.5 to 2.0. Compare the specific gravity of these base materials with, for example, aluminum which is approximately 2.7 and it is obvious that a significant savings in weight of the antenna and the waveguide feed can be achieved. In addition, polyetherimides and polyesters can be assembled using known processes such as those discussed above. Further, it is to be appreciated that assembly of injection molded pieces to make up the antenna and waveguide feed can be done by any of snap fits, adhesive bonding, solvent bonding, molded threads, inserts, ultrasonic bonding and others. Moreover, due to the superior physical properties of these base materials, a strong-lightweight array antenna and waveguide feed can be provided. Thus, an advantage of the antenna and waveguide feed **101** of the present invention that when molded from such base materials it has a structural strength and rigidity as well as resistance to environmental factors. In addition, an interior of each substantially rectangular waveguide can be effectively or environmentally sealed and inherently adapted for introduction of gas pressurization, if needed, for example to prevent moisture penetration.

The antenna of the present invention can also be provided with a plurality of steering arrays that can be co-located under the radome with the antenna array to aid in positioning the beam pattern of the antenna array. The steering arrays will be moved in azimuth and in elevation in conjunction with the antenna array so that the physical relationship between the steering arrays and the antenna array remain constant. FIG. **11** illustrates a plot in azimuth an elevation of an antenna beam pattern of the antenna array and the steering arrays. Each of the steering arrays has a corresponding antenna beam pattern **172**, **174**, **176**, **178** that is offset from the beam pattern **170** of the antenna array such as is illustrated in FIG. **11**. In particular, the steering array's beam pattern may be located for example, to the left in azimuth

172 and to the right 174 in azimuth of the beam pattern 170 of the antenna array, above 176 in elevation and below 178 in elevation the beam pattern of the antenna array. The signals received by the steering arrays can be processed in, for example, pairs such as the left-right pair and the up-down pair to aid in azimuth and elevation tracking of the antenna array. For example, the steering array patterns 172, 174, 176, 178 can be made to cross at the center of the beam pattern 170 of the antenna array so that equal amplitude signals are received from each steering array at the center of the beam pattern of the antenna array. Thus, if a large amplitude signal is received from the right steering array with respect to the left steering array, the antenna array can be moved to the left until an equal amplitude signal is received from both steering arrays. Similarly, the antenna can be moved in response to signals received from the up-down pair of steering arrays. Processing of signal output from the steering array outputs is amplitude based thereby eliminating a need for phase tracking between processing modules and permitting operation with a single channel processing chain.

FIG. 12 illustrates a possible location of the antenna subsystem 20 of the present invention on an aircraft 181. The antenna is located on the exterior of the aircraft, for example, on the top of the fuselage for a clear, unobstructed view in the direction of the satellite 26 under reasonable orientation of the aircraft. The system of the present invention may include satellite receivers 183 that may be located, for example, in a cargo area of the aircraft. In addition, the system may include seat back video displays 187, associated headphones and a selection panel to provide channel selection capability to each passenger. Alternatively, video may also be distributed to all passengers for shared viewing through a plurality of screens placed periodically in the passenger area of the aircraft. Further, the system may also include a system control/display station that may be located, for example, in the cabin area for use, for example, by a flight attendant on a commercial airline to control the overall system and such that no direct human interaction with the equipment is needed except for servicing and repair.

As discussed above, the antenna 28, the steering arrays and the waveguide feed 34 can be used to make up the satellite tracking antenna subsystem 20 that can be used a s the front end of a satellite video reception system on a moving vehicle such as the aircraft of FIG. 12. The satellite video reception system can be used to provide to any number of passengers within the aircraft with live programming such as, for example, news, weather, sports, network programming, movies and the like. In particular, the antenna will track the motion of the vehicle in azimuth and in elevation to keep the antenna beam pattern focused on the transmitting satellite 26, will receive the live broadcast video signals from the transmitting satellite, and will present the live broadcast video signals to a receiver system 186 which will distribute the desired programs to each passenger, as selected by each passenger.

One problem with providing a signal such as, for example, any of a live video programming signal, or a communications signal such as a telephone signal, or interactive services such as internet services, or other data signals to passengers in a vehicle such as, for example, an aircraft during a transoceanic flight is that satellites or ground communication stations are not always positioned so as to provide the signal to the moving vehicle for the entire path of its trip. According to the present invention, a method of providing a signal to passengers in a vehicle in an area where the signal is not available such as, for example, an area that is not within the coverage area of an existing satellite, or an area where ground to air communications are not available, or an area where continuous coverage is not available, or an area where a signal quality is poor includes receiving the signal with a first receiver in an area where the signal is available. It is to be appreciated that according to this specification, an area where there is not continuous satellite coverage is defined as any area where a signal cannot be continuously received such as, for example, over the Atlantic Ocean where if one satellite is positioned over the Atlantic, a transmitted signal may be a drop off in strength for portions of the Atlantic Ocean but provide an adequate signal for other portions of the Atlantic Ocean.

For a transoceanic flight, the first receiver may be located on a communications tower positioned on the ground to communicate with an aircraft that is about to begin or has just begun the transoceanic portion of the flight or may be located on an aircraft itself that is still within the coverage area of a satellite as it flies over or near a coast line. Since, as is known to those aviation industry, flights such as, for example, transatlantic flights occur at approximately the same altitude wherein a plurality of aircraft travel across the Atlantic Ocean in a set of parallel paths, known as "tracks" forming rows of aircraft spaced at, for example, two minutes apart one in front of another, a next step in the method of providing the signal to the passengers is to retransmit the received signal by the first receiver to a second receiver that is located, for example, on an aircraft that is in a back of the track of aircrafts making the transoceanic flight. An additional step in the method is to receive the retransmitted signal with the second receiver and to then retransmit the received signal from the second receiver to a third receiver located on another aircraft that is, for example, located in front of the aircraft housing the second receiver. This step can be repeated along the track of aircrafts across the entire ocean to provide any of the live video programming, two-way communications signals, or interactive services, or other data signals to each passenger within the plurality of aircraft crossing the ocean.

Although this example has been provided with respect to aircraft in a transoceanic flight pattern, it is to be appreciated that this method can be applied to any aircraft anywhere in the world where the flight path is not within a coverage area of a transmitting satellite, or where ground to air communications signals are not available, or where continuous satellite or communications signal coverage is not available, or where signal reception quality is poor. It is also to be appreciated that although this example has been illustrated with each aircraft receiving and retransmitting the signal, this method can be used where only some of the aircraft receiving and retransmitting the signal and with others, for example, only receiving the signal and not retransmitting the signal. It is further to be appreciated that although this method has been described with respect to aircraft, it can be applied to any vehicle such as, for example, a plurality of automobiles driving in any area of any country within the world that is not within any of the above-described signal coverage areas.

Having thus described several particular embodiments of the invention, various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be part of this disclosure, and are intended to be within the spirit and scope of the invention. Accordingly, the foregoing description is by way of example only and is limited only as defined in the following claims and the equivalents thereto.

What is claimed is:

1. A system that provides information to a second passenger vehicle, to create an information network where there is no existing fixed communication channel between the second passenger vehicle and an information source, the system comprising:

a first transmitter/receiver unit disposed on a first passenger vehicle and adapted to provide the information to a first passenger associated with the first passenger vehicle;

an antenna coupled to the first transmitter/receiver unit and adapted to receive an information signal that includes the information from the information source and to re-transmit the information signal;

a receiver located on the second passenger vehicle, the receiver being adapted to receive the information signal, and to provide the information for access by a second passenger associated with the second passenger vehicle; and

an additional transmitter/receiver unit that receives the information signal and transmits the information signal, to provide the information signal between the first transmitter/receiver unit and the receiver.

2. The system as claimed in claim **1**, wherein the additional transmitter/receiver unit is located on a fixed platform.

3. The system as claimed in claim **1**, wherein the first passenger vehicle is in an area where no satellite coverage is available.

4. The system as claimed in claim **1**, wherein the first passenger vehicle is in an area where satellite coverage is available.

5. The system as claimed in claim **1**, wherein the information signal is a video programming signal.

6. The system as claimed in claim **1**, wherein the information is maintenance information for the second passenger vehicle.

7. The system as claimed in claim **1**, wherein the information signal includes positional information of the first passenger vehicle.

8. The system as claimed in claim **1**, wherein the information is vital information for at least one of the first and second passengers.

9. The system as claimed in claim **1**, wherein the information is Internet-related data.

10. The system as claimed in claim **1**, wherein the information is telecommunications data.

11. The system as claimed in claim **1** wherein the additional transmitter/receiver unit is located on a third passenger vehicle.

12. The system as claimed in claim **11**, wherein each passenger vehicle travels along a line of travel, and wherein the receipt and transmission of the information signal between each of the passenger vehicles is along the line of travel.

13. The system as claimed in claim **12**, wherein each of the passenger vehicles is an aircraft and the information network is a sky network.

14. The system as claimed in claim **13**, wherein the aircraft are located on a flight track, and wherein the line of travel is along the flight track.

15. The system as claimed in claim **11**, wherein each passenger vehicle is a ground vehicle, and wherein the information signal between the ground vehicles creates a network for the information signal.

16. The system as claimed in claim **1**, wherein the antenna is a directional antenna having focused transmit and reception patterns.

17. The system as claimed in claim **1**, wherein the antenna is an omni-directional antenna.

18. The system as claimed in claim **1**, wherein the information includes weather information.

19. The system as claimed in claim **1**, wherein the additional transmitter/receiver unit is located on a satellite.

20. The system as claimed in claim **1**, further including a radome that at least partially surrounds the antenna and that is transmissive to the information signal provided to and from the antenna.

21. A method for providing information from a source to a second passenger vehicle, the method comprising steps of:

transmitting an information signal including the information from the source;

receiving the information signal with a first transmitter/receiver unit located on a first passenger vehicle;

providing the information for access by a passenger associated with the first passenger vehicle;

re-transmitting the information signal with the first transmitter/receiver unit;

repeating the steps of receiving the information signal and re-transmitting the information signal with at least one additional transmitter/receiver unit to provide the information signal between the first transmitter/receiver unit and the second passenger vehicle;

receiving the information with a receiver located on the second passenger vehicle; and

providing the information for access by a passenger associated with the second passenger vehicle.

22. The method as claimed in claim **21**, wherein the steps of re-transmitting the information signal include re-transmitting the information signal between the passenger vehicles along a line of travel of the passenger vehicles.

23. The method as claimed in claim **21**, wherein the at least one additional transmitter/receiver unit is located on a corresponding at least one passenger vehicle.

24. The method as claimed in claim **21**, wherein the passenger vehicles are aircraft, and wherein the steps of re-transmitting the information signal include re-transmitting the information signal along a flight track along which the aircraft are travelling.

25. The method as claimed in claim **21**, wherein the steps of transmitting and re-transmitting the information signal are performed by transmitting the information signal in a focused transmit pattern to a respective transmitter/receiver unit.

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